PATENT
29250-000434/US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	Peretz Moshes FEDER et al.	Conf. No.:	2613
Appl. No.:	09/652,153	Group:	2154
Filed:	August 31, 2000	Examiner:	Dustin Nguyen
For:	A METHOD FOR TRANSMITTING DATA OVER A NETWORK MEDIUM		

DECLARATION UNDER 37 C.F.R. §1.131

United States Patent and Trademark Office
Customer Service Window, Mail Stop Amendment
Randolph Building
401 Dulany Street
Alexandria, VA 22314

Sir:

We, Peretz Moshes Feder and Chih-Peng Li, hereby declare and state:

1. We are the co-inventor of all of the originally filed claims of the above-identified patent application.

2. The application is assigned to Lucent Technologies Inc., as recorded on April 12, 2001, at REEL 011717 and FRAME 0638.

3. Prior to May 14, 1999, we conceived the method for transmitting data over a network medium as described and claimed in claims 1-24, which are presently pending in the application.

4. Prior to May 14, 1999, we disclosed our invention to others within Lucent Technologies, Inc.

5. Prior to May 14, 1999, we prepared and submitted a written description of the invention to Lucent Technologies' legal department for preparation of a patent application. A copy of the invention disclosure, with dates redacted, is attached as Exhibit A.

6. The submission of the invention disclosure to Lucent Technologies' legal department resulted in a request that outside counsel prepare a draft application.

7. Outside counsel prepared the present patent application in regular order. We reviewed and approved the patent application before it was filed on August 31, 2000.

8. Each of the above-listed acts occurred in the United States.

9. We hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Peretz Moshes FEDER — Date

Chih-Peng LI — Aug 22, 2005. Date

EXHIBIT A

Subject: Alternative Algorithms for Improving Binary Exponential Backoff (BEB) Collision Resolution Algorithm

Technical Memorandum

I. Introduction

Several types of multiple access protocols have been proposed for wireless communications. First, fixed-assignment protocols allocate the channels in a deterministic way, e.g., TDMA (time division multiple access) and FDMA (frequency division multiple access). These types of protocols are widely implemented in 2^{nd} generation of cellular networks such as GSM and IS-54/136. However, these schemes are inefficient in bandwidth utilization for bursty data and do not take the full advantage of speech traffic characteristics.

A second type of multiple access technique is CDMA (code division multiple access). CDMA is adopted in IS-95 and many of the 3^{rd} generation cellular systems. CDMA is a special application of the generic spread spectrum (SS) techniques [1]. In general, there are three approaches to implement SS systems: (I) Direct Sequence Spread Spectrum (DSSS); (II) Frequency-Hopping Spread Spectrum (FHSS); (III) Time-Hopped Spread Spectrum (THSS).

A third type of scheme, random access, adopts packet contention techniques, such as Slotted ALOHA and CSMA (carrier sense multiple access), to accommodate a large number of users, each with a low average data rate and a high peak rate. This type of protocol and its extensions are widely implemented in many standards, e.g. CSMA/CD (collision detection) in 802.3 and CSMA/CA (collision avoidance) in 802.11. Although the random access schemes operate with no centralized coordination, these schemes result in very low throughput and substantial transmission delay [2].

The last type is the demand-assignment protocols, in which users make bandwidth reservation when they need it. Several major Medium Access Control (MAC) protocols in this category have been proposed. The first category as proposed in [2,3,4,5,6] is Packet Reservation Multiple Access (PRMA), which is closely related to the reservation ALOHA protocol, R-ALOHA [7]. PRMA is adopted as one of the major European Community candidate access techniques for the third generation of mobile systems [8]. A variety of modifications have been made on PRMA for different applications, e.g. [9,10].

The second major category of demand-assignment MAC protocol is Distributed Queuing Request Update Multiple Access (DQRUMA) [11,12], in which request of bandwidth is made through a requesting access channel (RA channel). Any random access protocol can be used for

the RA channels and any scheduling algorithm can be used by the base station for allocating bandwidth to mobiles in the uplink direction.

The third major category is Resource Assignment Multiple Access (RAMA) [13,14,15]. RAMA uses a 10-digit decimal ID during the contention cycle and can be viewed as an extension of the Binary Countdown protocol, as implemented in AT&T's DATAKIT, to M-ary countdown. A modification of RAMA, called Tree-search RAMA (TRAMA), can be found in [16].

A Random Addressed Polling (RAP) [17] was proposed to IEEE 802.11 committee. Its extension Group Randomly Addressed Polling can be found in [18]. Several other MAC protocols proposed for wireless ATM are summarized in [19]. An extensive discussion of generic MAC protocols, including IEEE 802 family, can be found in [20].

All the random access schemes, such as Slotted ALOHA and CSMA/CD, and many of the demand-assignment schemes, such as PRMA and DQRUMA, rely on Collision Resolution algorithms when collision occurs, either in data transmission or in bandwidth reservation. Three major classes of collision resolution algorithms have been found from the literatures: (I) Binary Exponential Back-off (BEB); (II) Splitting Algorithms, also known as Tree Algorithm; (III) Adaptive p-persistence Algorithm. Perhaps BEB is the most well-known one and is adopted in many MAC standards such as 802.3 and MCNS CATV [21]. With BEB, there is no need for each user to detect the channel condition of idle, successful transmission, and collision. All each user needs is whether or not its own packets were successfully transmitted; it receives no feedback about slots in which it does not transmit. The maximum throughput of BEB is 0.3679.

Tree algorithm is more sophisticated, but also increases the achievable throughput. As opposed to BEB, tree algorithm depends on the feedback of each slot. [22] has an extensive description and analysis of the operation of tree algorithm and its modifications. The maximum stable throughput achievable falls somewhere between 0.4878 and 0.587.

It has been shown that the infinite population slotted ALOHA channel with Poisson arrivals and fixed retransmission probabilities was inherently unstable [23]. Numerous papers have been focus on adaptive p-persistence algorithms [24,25,26]. In principle, this algorithm estimates p using the transmission result of the channel.

Although BEB has been widely implemented in many systems, it has been found that BEB leads to a "capture effect" whereby a single or a few hosts can dominate packet transmission despite other stations also having packets queued for transmission [27,28]. Several solutions have been proposed toward this problem for Ethernet [29,30].

In the XWD wireless internet access system, traffic in the downlink direction is scheduled by the access point (bast station). In the uplink direction, if a packet arrives at an empty queue, the packet has to reserve bandwidth through reservation slots and waits for bandwidth allocation from the beacon message of access point. If reservation goes through the reservation slot successfully, bandwidth will be granted by the access point and the packet will be transmitted without contention. If reservations collide in the reservation slots, each individual reservation

has to back-off and waits a random period of time for retransmission. The back-off algorithm currently implemented is the traditional BEB. If a packet arrives at a non-empty queue, bandwidth reservation will be made by piggyback.

In this work, we explore two alternative back-off algorithms which have better performance over the traditional BEB. Just like BEB, the proposed algorithms do not rely on the feedback of each slot. In section II, we describe the system and traffic models we adopted in the simulation. Section III provides detail descriptions of the proposed back-off algorithms. Simulation results are shown and discussed in section IV. The performance measures we adopted are average delay, standard deviation of delay, throughput, and probability of dropping. Section V summarizes this work.

II. System and Traffic Model

In this memorandum, we assume there are N reservation slots in each uplink frame, where N = 1, 2, or 4. Besides, we assume there are U users in the system, where U=2, 4, 8, 16, 32, 64, 128, 256, 512, or 1024. For each user, when a reservation is successfully made, the next reservation will be initiated X frames later, where X is exponentially distributed with a mean arrival time of 2, 8, 32, 128, or 512 frames. From the instant when a reservation is generated, until the moment the reservation is successfully made, there is no additional reservation being initiated.

III. Proposed Back-Off Algorithms

The traditional BEB algorithm operates in the following way: an immediate first transmission is made as soon as a new reservation is generated. If a reservation has been transmitted unsuccessfully i times, then the reservation will be retransmitted again k slots later, where k is a random number uniformly distributed over the interval of $[1, 2^i]$. If i is greater than 10, k is uniformly distributed over the interval of [1, 1024]. From now on, we will refer the interval over which the uniformly distributed number is drawn as back-off window. If i is greater than 16, the reservation is expired and dropped. If a reservation is successfully made or is expired and dropped, i is reset to 0. The philosophy behind the traditional BEB algorithm is that, for a given reservation, a higher value of unsuccessful transmission implies that more users are contending for the available bandwidth, and, as a result, a larger back-off window size should be opened.

One result of the traditional BEB algorithm is last-come-first-serve among competing users. An user that has a newly generated reservation, either after a successful transmission or after a dropped reservation, has a much higher probability of acquiring the medium in a collision than those stations that have already experienced couple of collisions. This result leads to the "capture effect" that allows a single or a few "winning" stations to dominate the available bandwidth. From another point of view, larger number of retransmissions of a given reservation may not be due to larger number of competing users. It may be the consequence of capture effect. One possible solution toward this problem is that the back-off window size does not grow exponentially with the number of retransmissions. In other words, more opportunity should be granted to a given reservation before the back-off window size is doubled.

In the traditional BEB algorithm, an immediate first transmission is made as soon as a new reservation is initiated. This is a reasonable approach when the system load is not high. However, when many users are contending for the medium, the immediate first transmission worsens the probability of collision. One possible solution to this problem is that a newly generated reservation should go into back-off immediately with a back-off window size equal to half of previous back-off window size. When the system load is light, the window size is small most of the time. Under such condition, this modification has only minor effect on the performance. When the system load is heavy, since the back-off window size is big most of the time, this modification keeps the back-off window at a reasonable size so that unnecessary collisions can be avoided.

Based on the previous discussions, we develop the following two algorithms:

A. Double Binary Exponential Back-Off (DBEB)

i	1	2	3	4	5	6	7	8	9	10
Window(i)	2	2	4	4	8	8	16	16	32	32
i	11	12	13	14	15	16	17	18	19	20
Window(i)	64	64	128	128	256	256	512	512	1024	1024

1. If(collision){
    $i = i + 1$;
    if(i >= 20) i = 20;
    back-off window = window(i);
}
2. If(success or expiration){
    $i = i$ -2;
    back-off window = window(i);
}
3. Minimum back-off window is equal to the number of reservation slots per frame.

B. Half Binary Exponential Back-Off (HBEB)

I	1	2	3	4	5	6	7	8	9	10
Window(i)	2	3	4	6	8	12	16	24	32	48
I	11	12	13	14	15	16	17	18	19	
Window(i)	64	96	128	192	256	384	512	768	1024	

1. If(collision){
    $i = i + 1$;
    if(i >=19) i = 19;
    back-off window = window(i);
}
2. If(success or expiration){
    $i = i$ -2;
    back-off window = window(i);

}

3. Minimum back-off window is equal to the number of reservation slots per frame.

IV. Simulation Results and Discussions

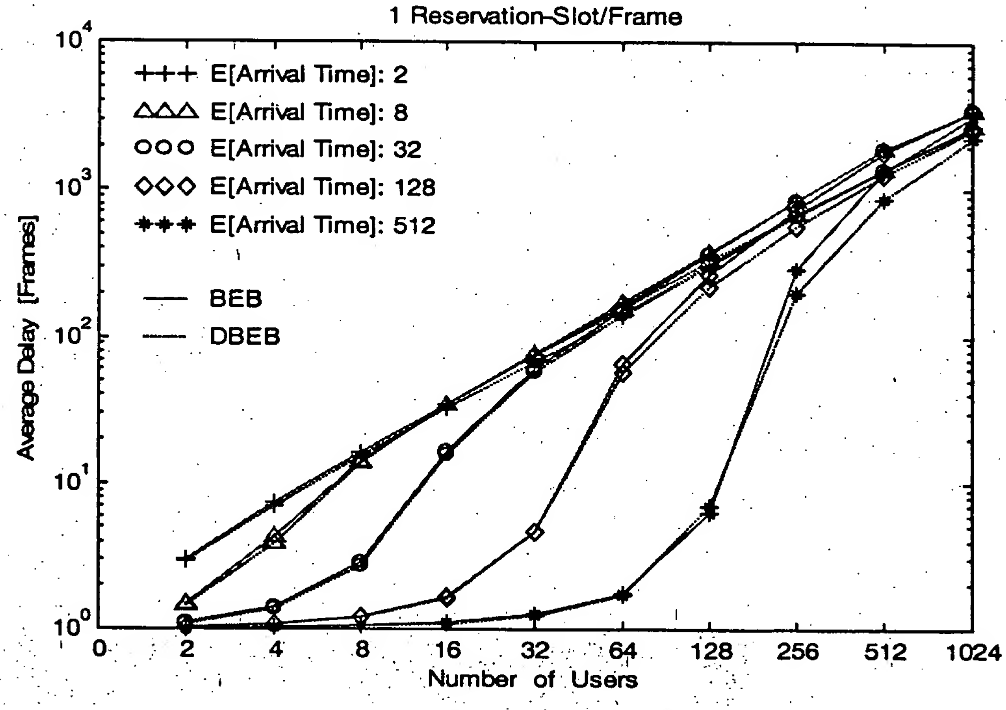

Figure - 1.

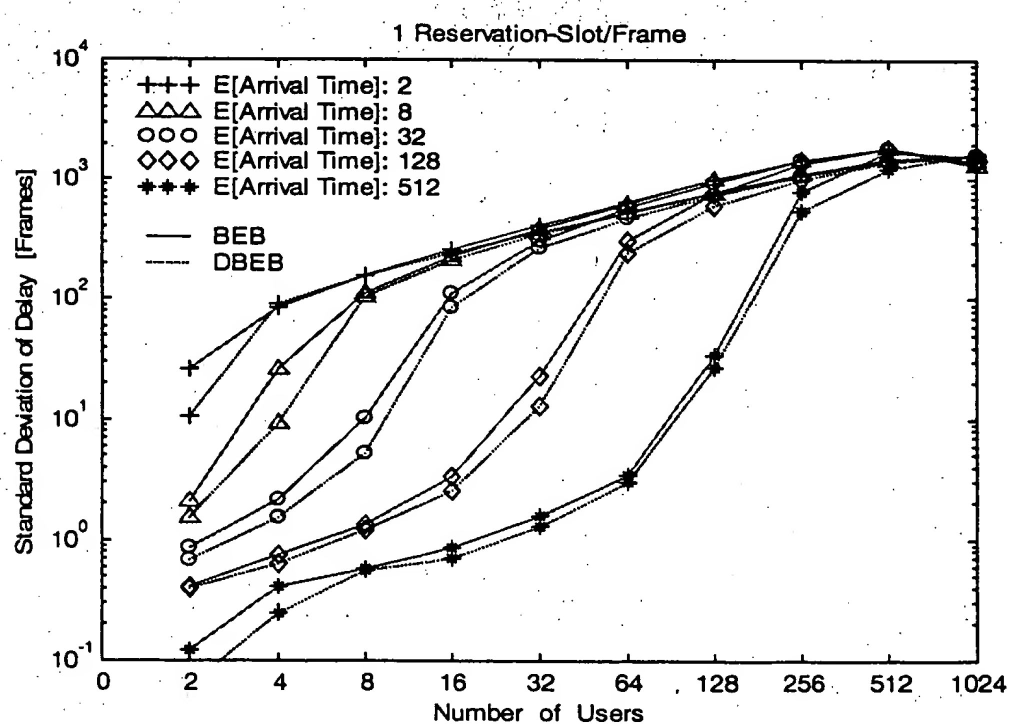

Figure - 2.

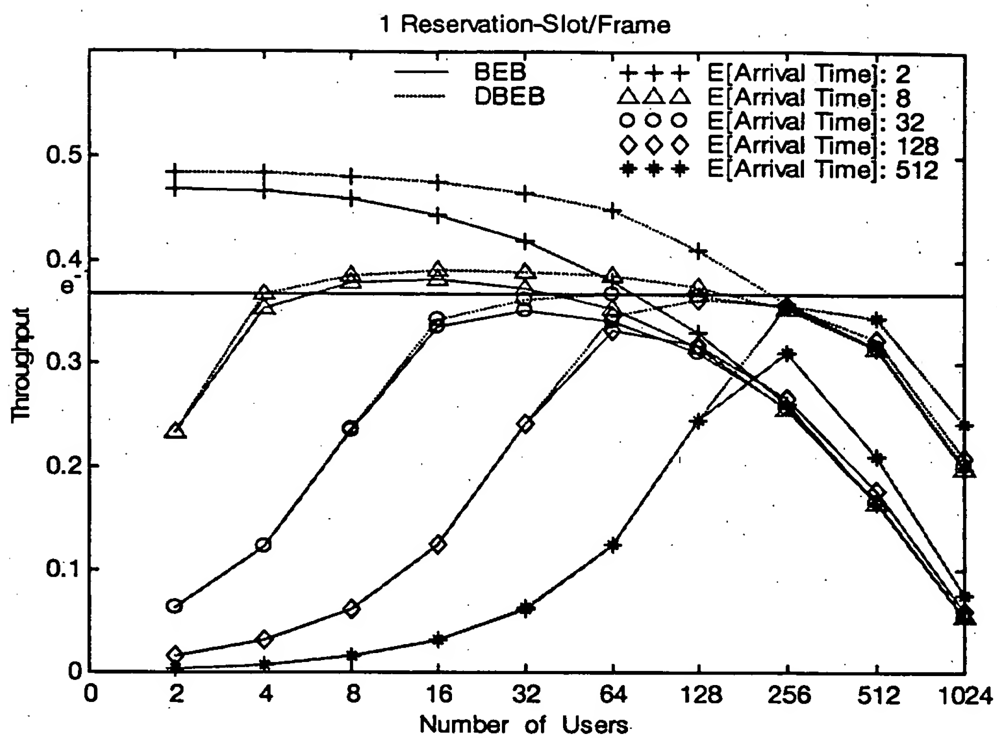

Figure – 3.

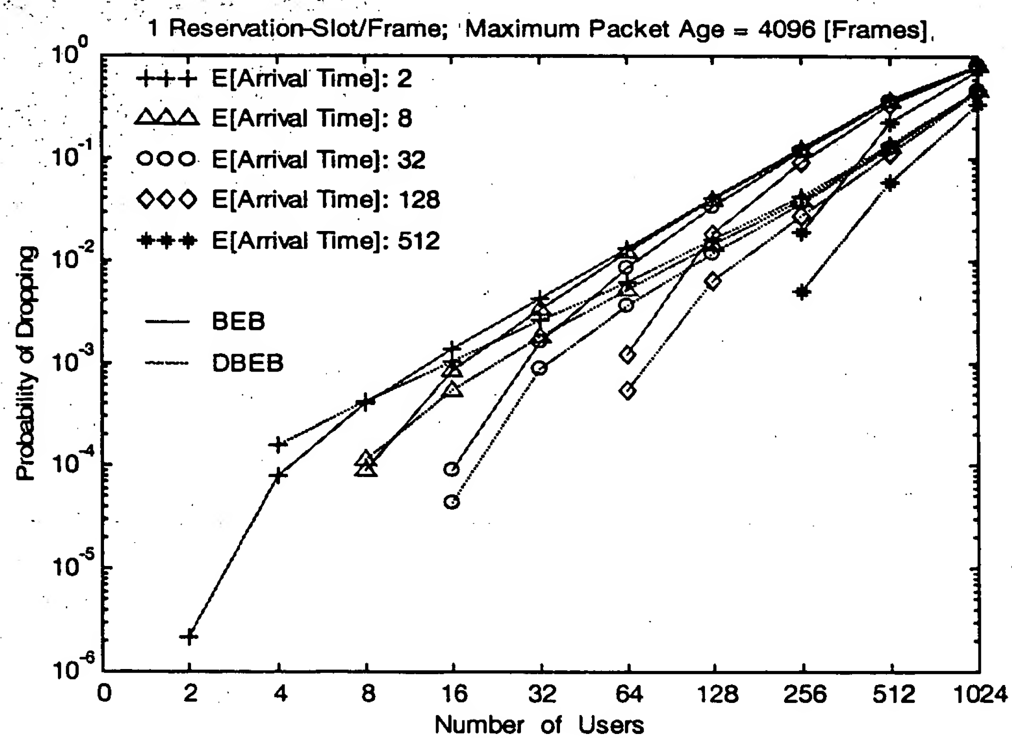

Figure – 4.

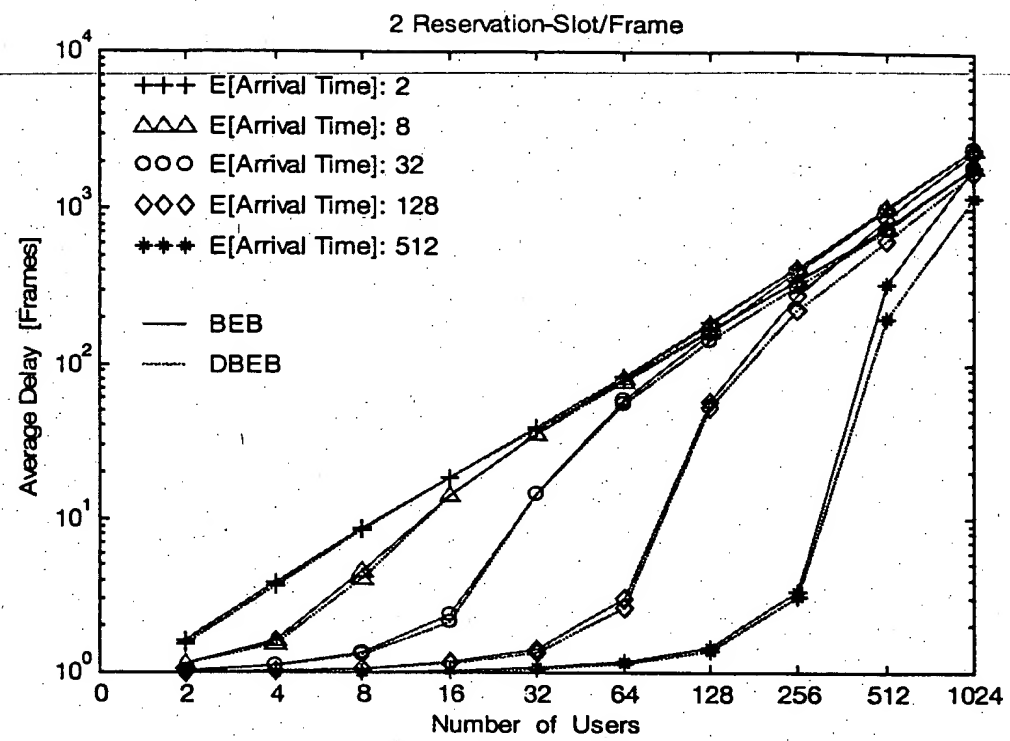

Figure – 5.

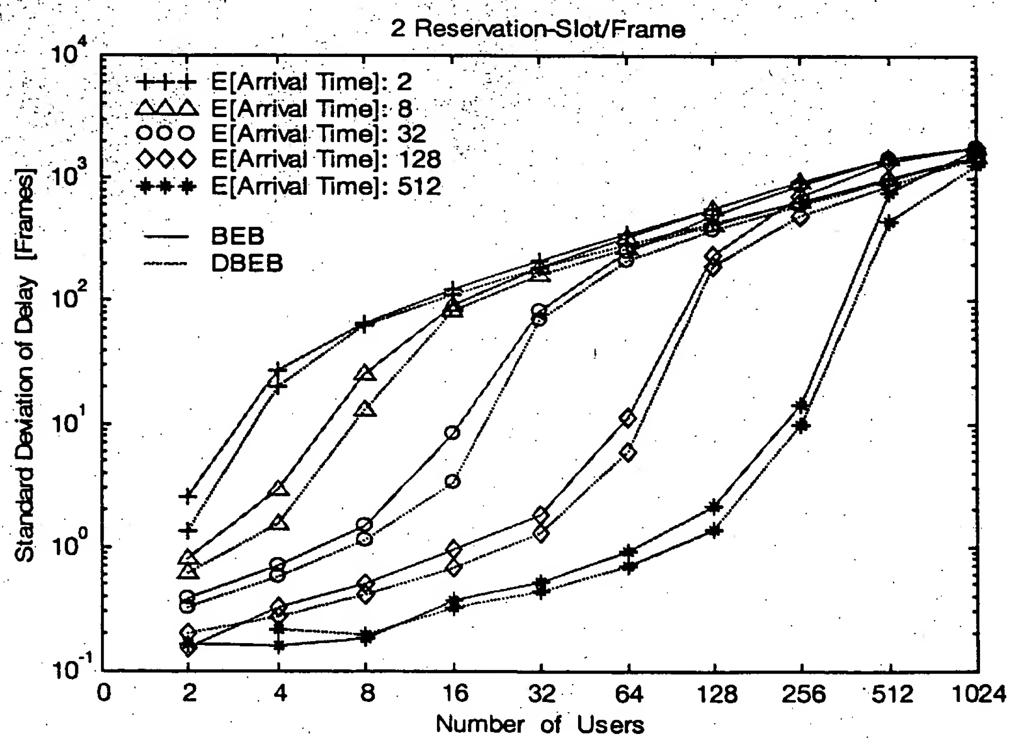

Figure – 6.

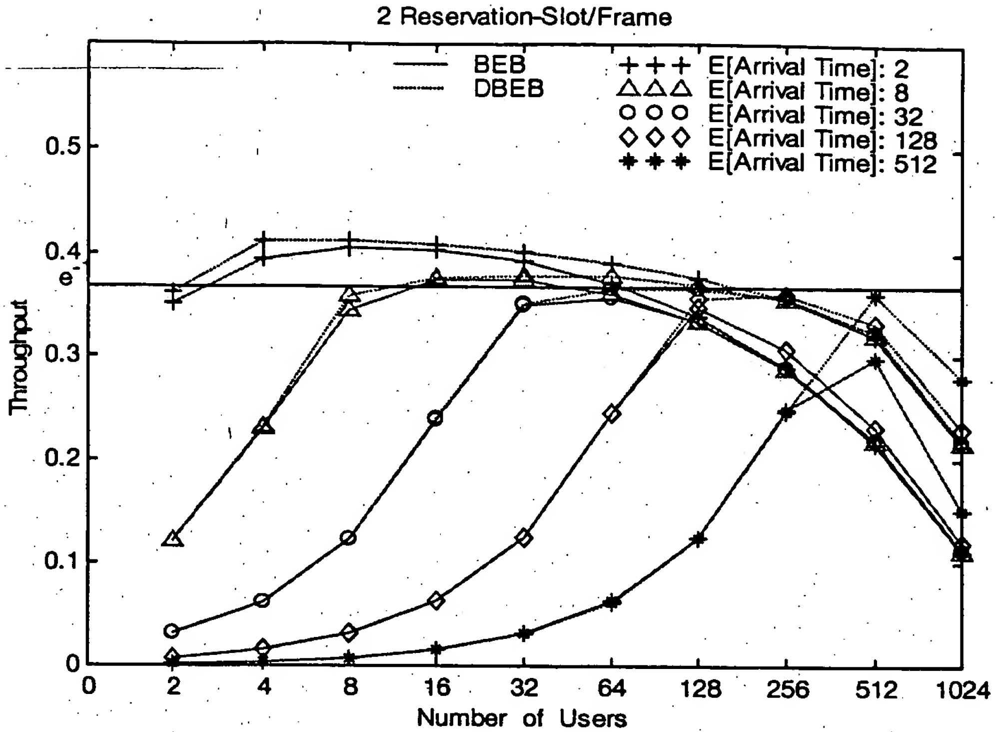

Figure – 7.

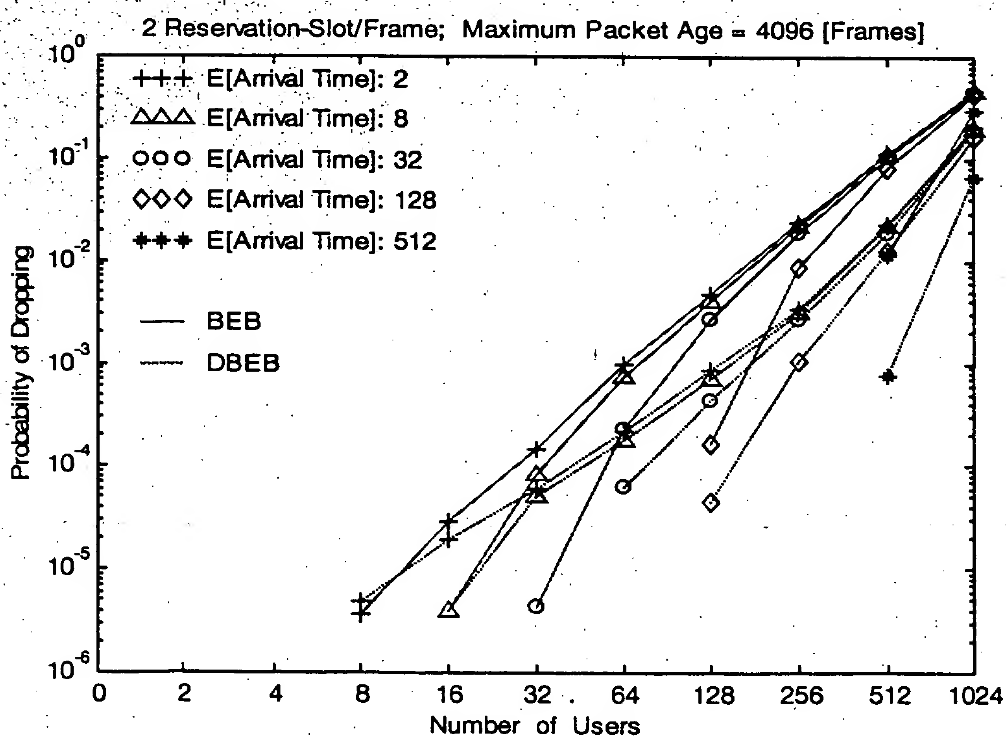

Figure – 8.

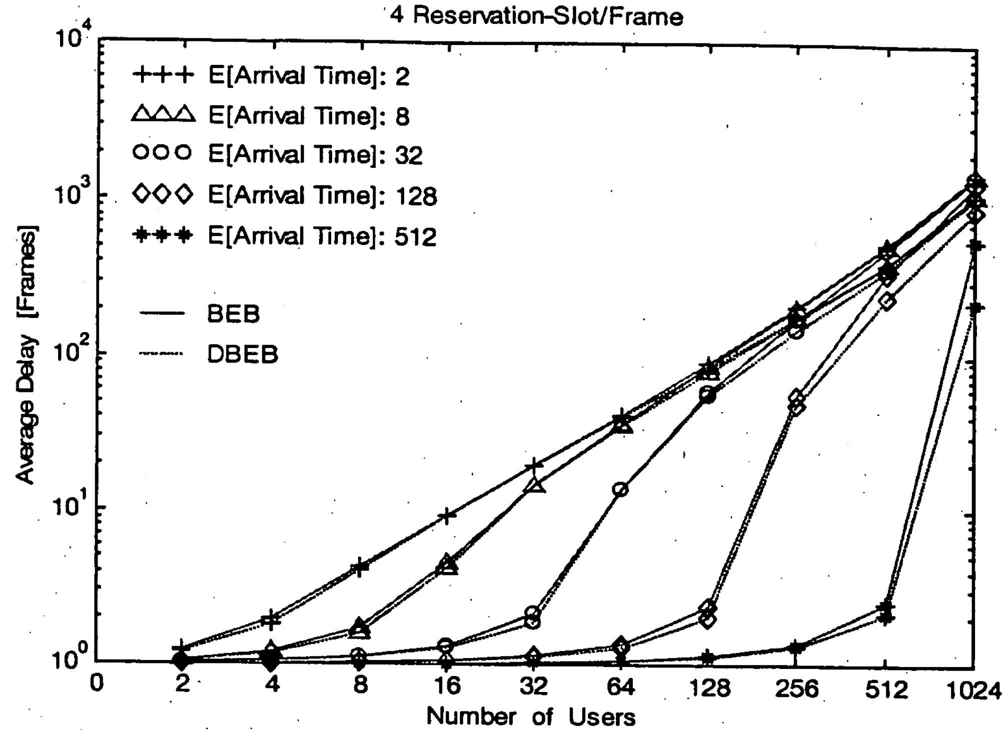

Figure – 9.

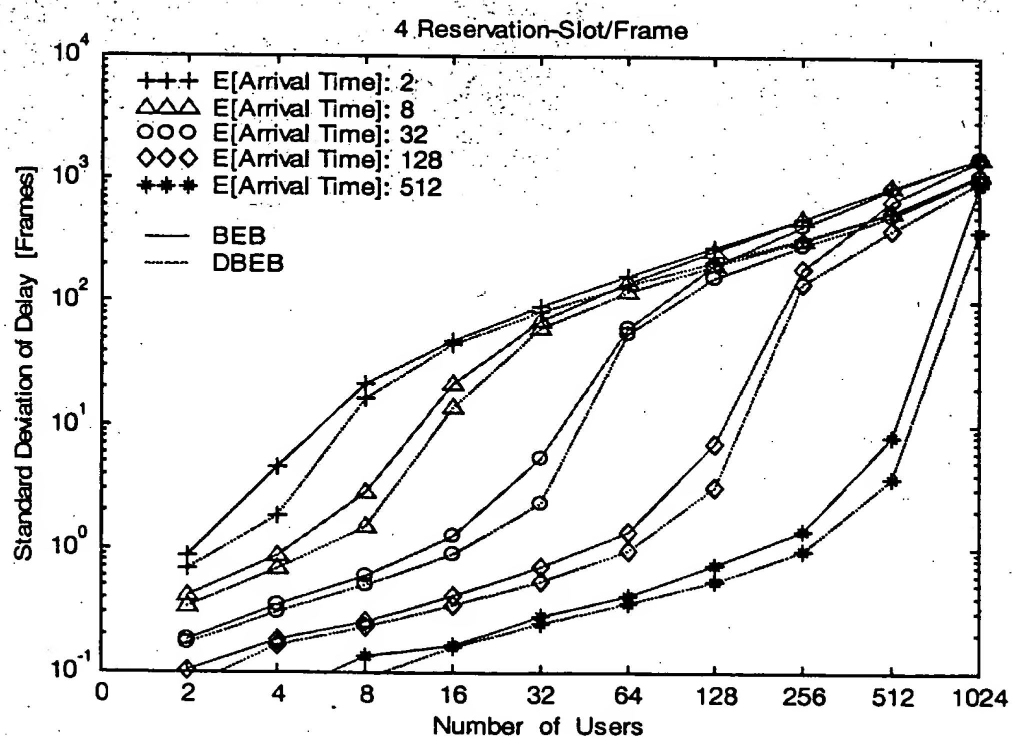

Figure – 10.

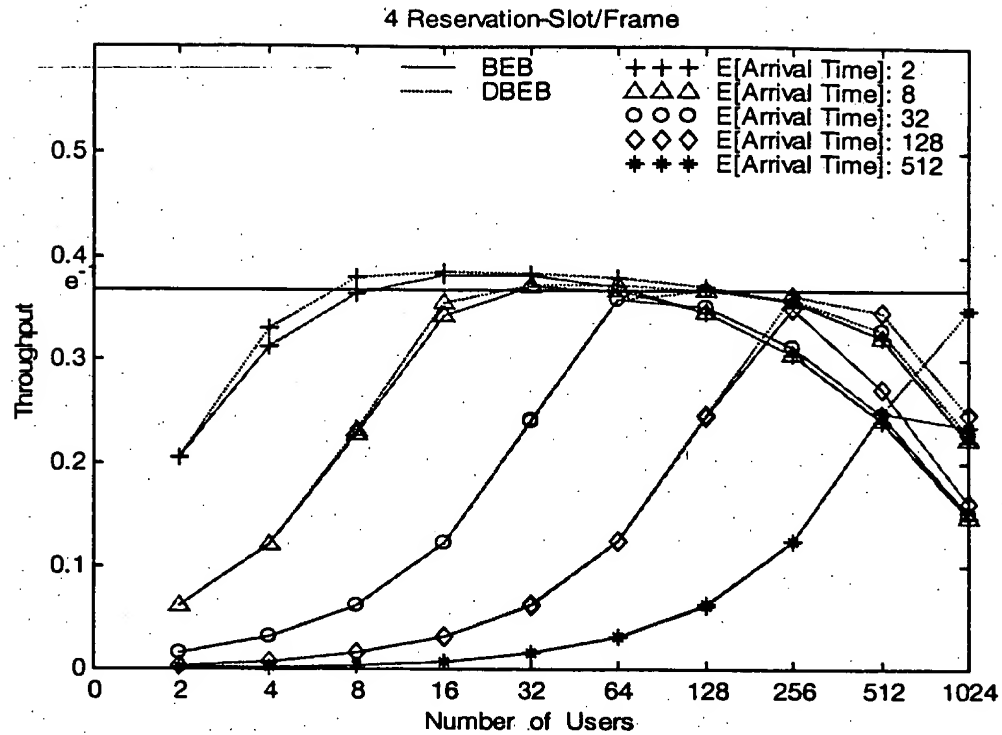

Figure – 11.

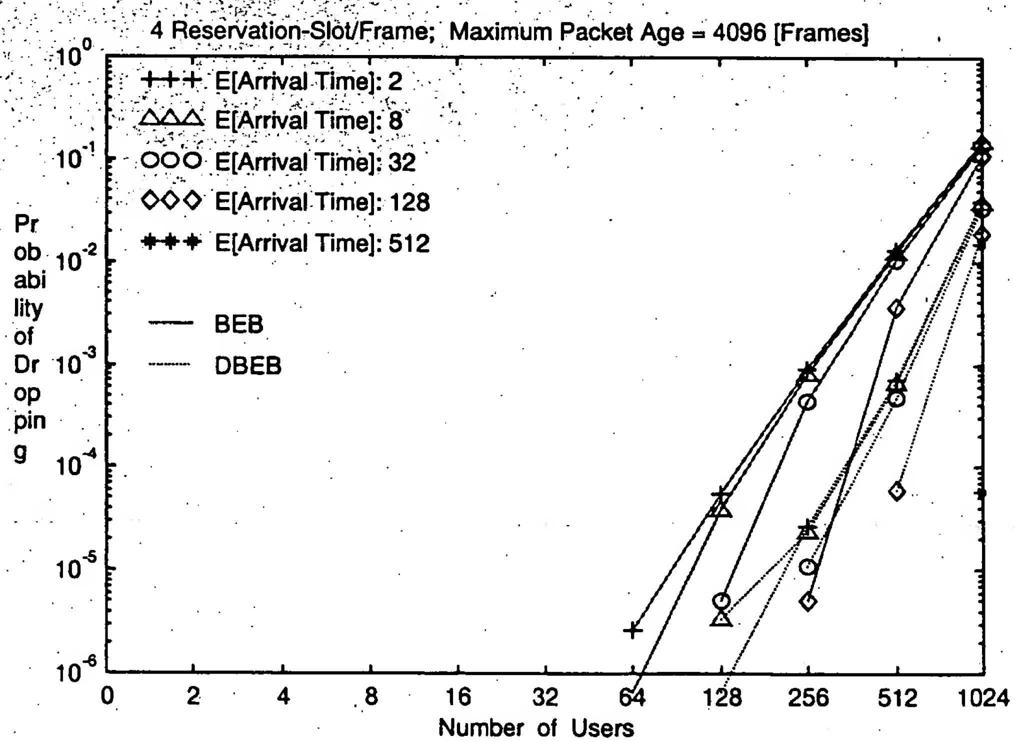

Figure – 12.

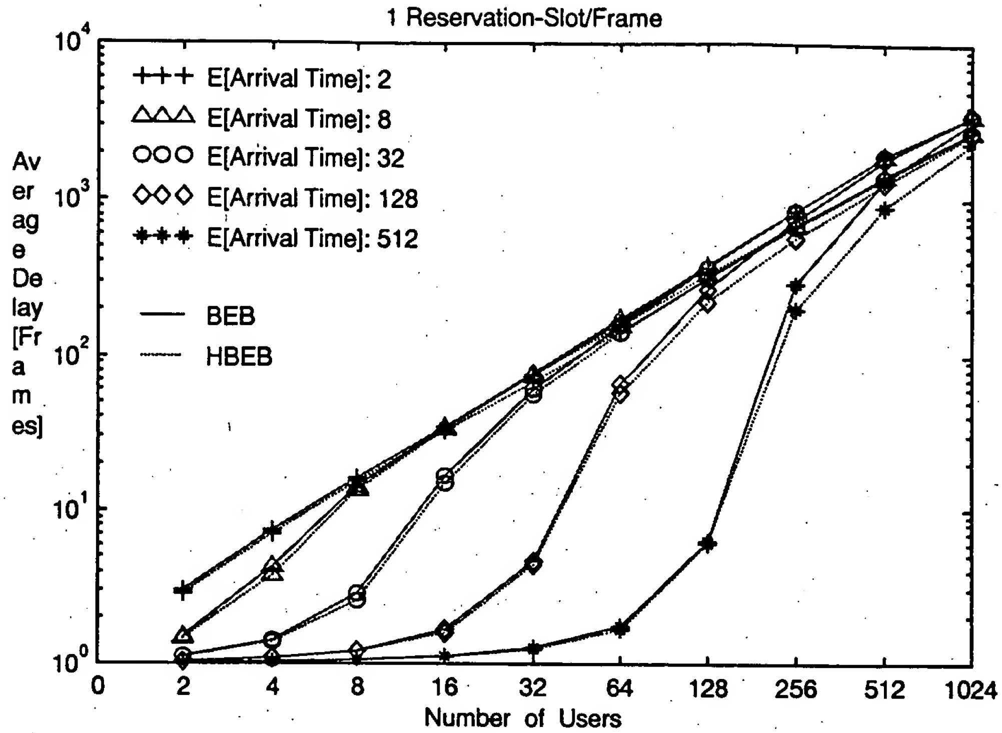

Figure – 13.

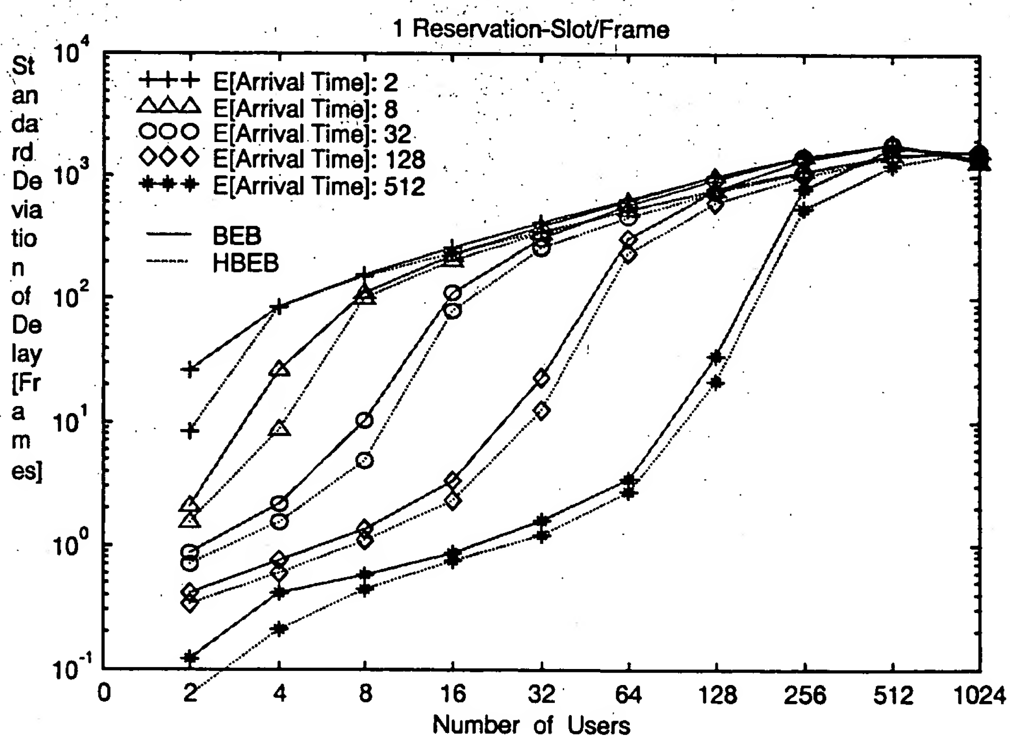

Figure – 14.

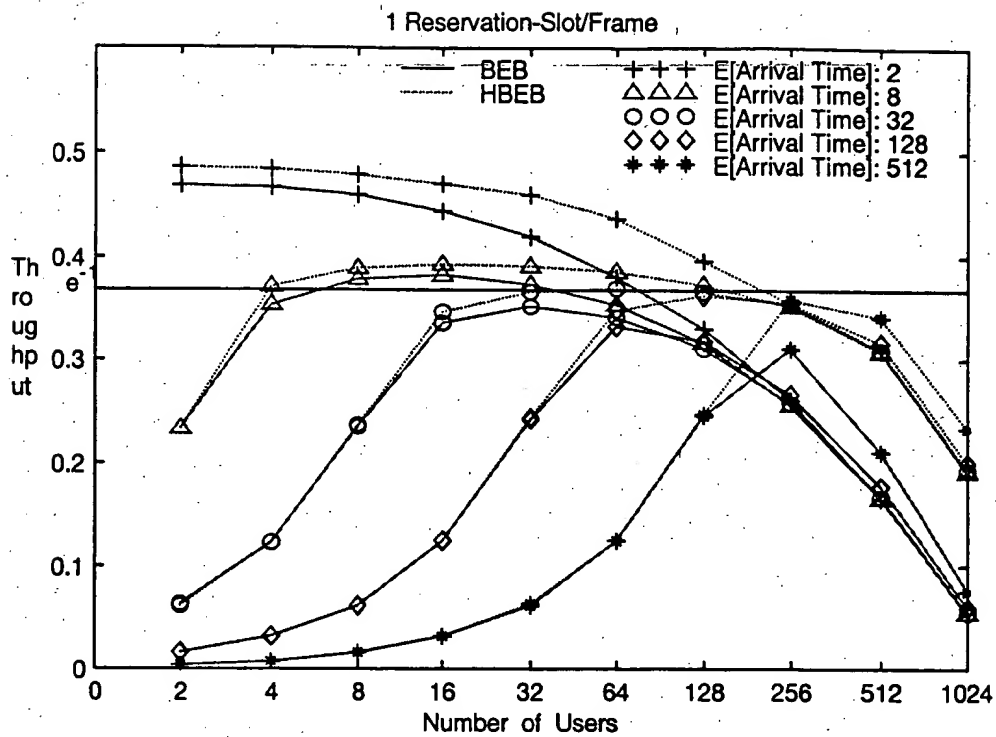

Figure – 15.

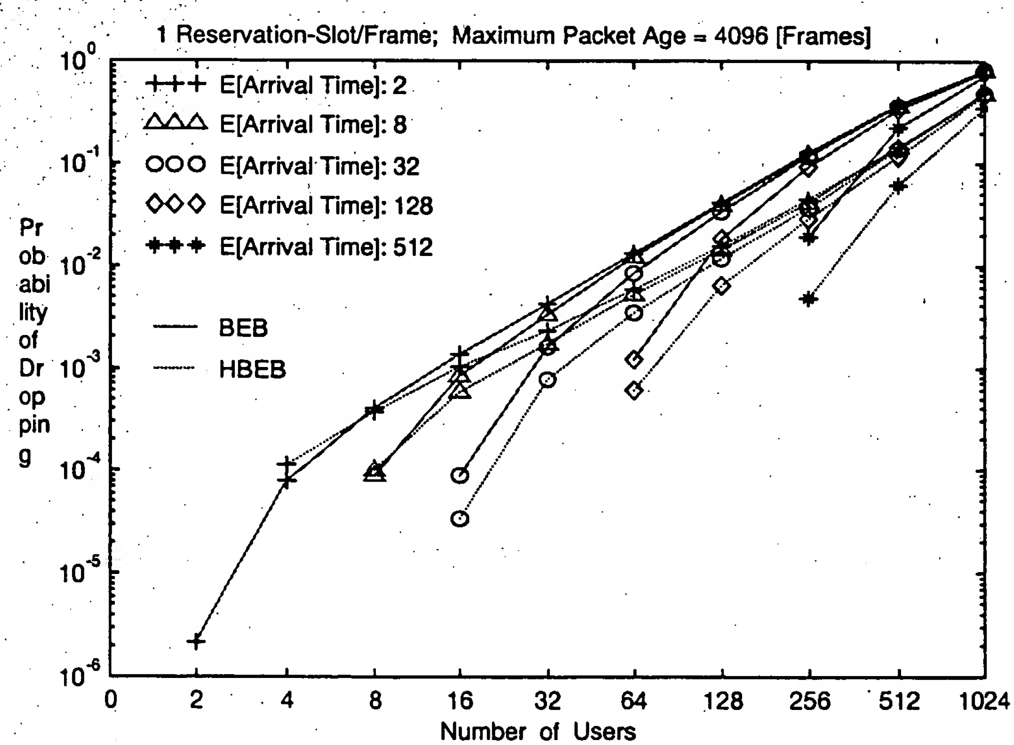

Figure – 16.

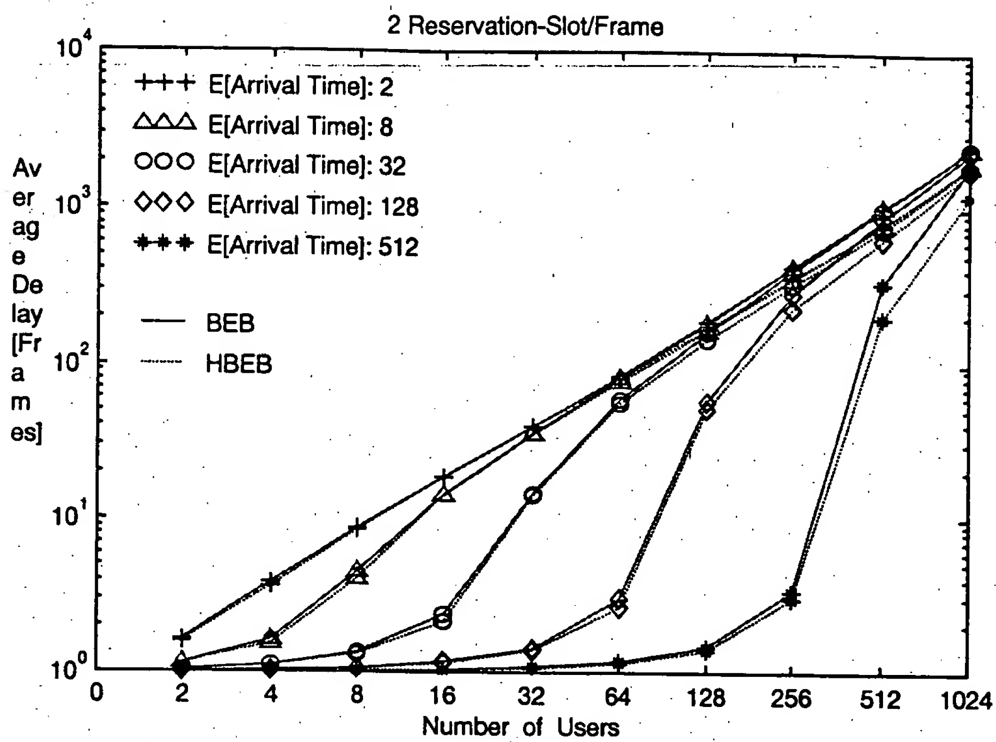

Figure – 17.

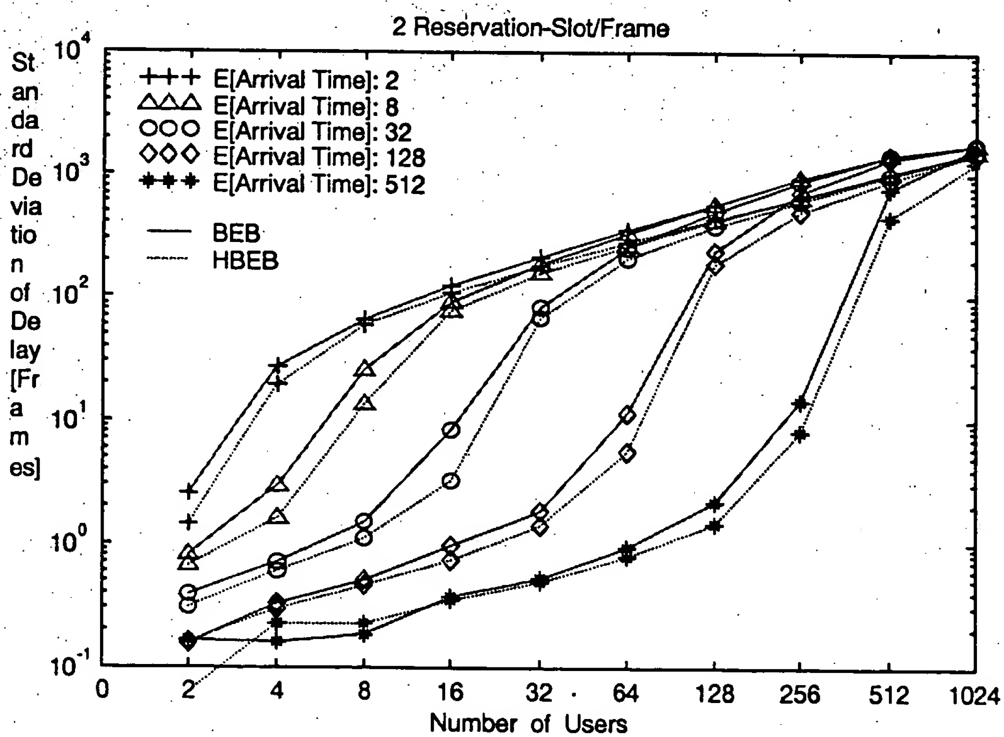

Figure – 18.

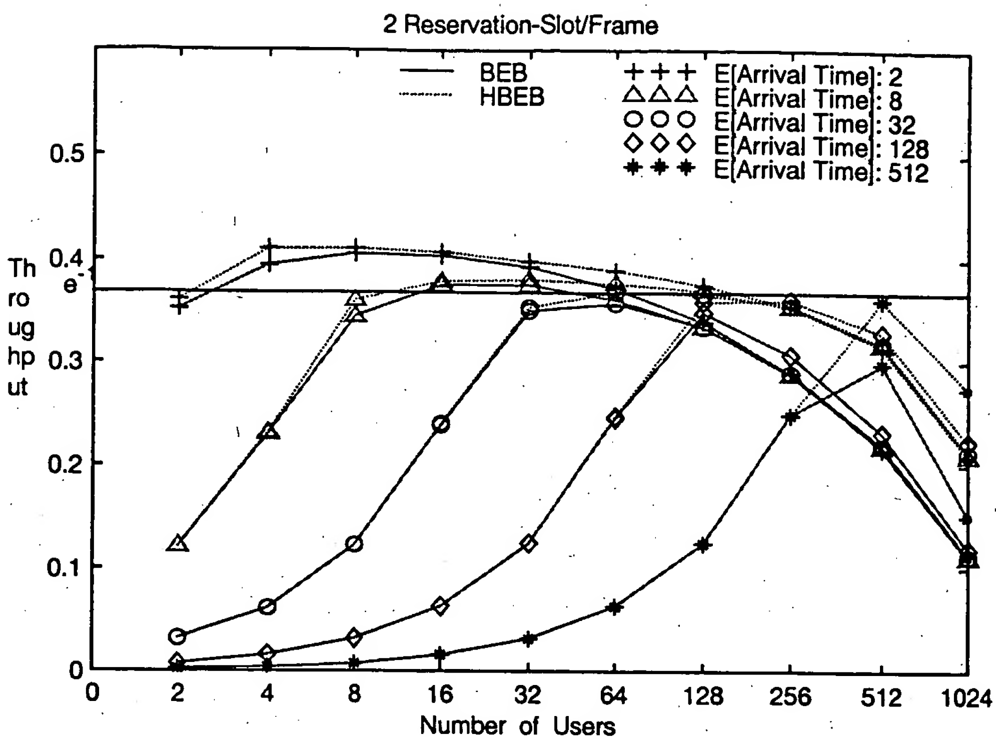

Figure – 19.

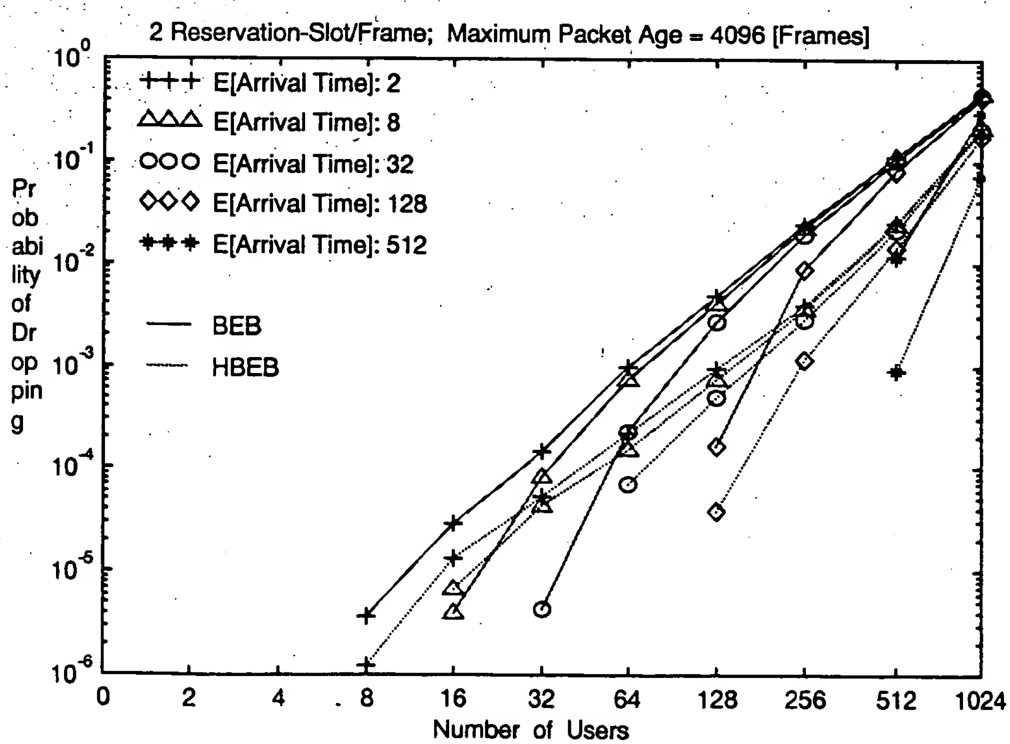

Figure – 20.

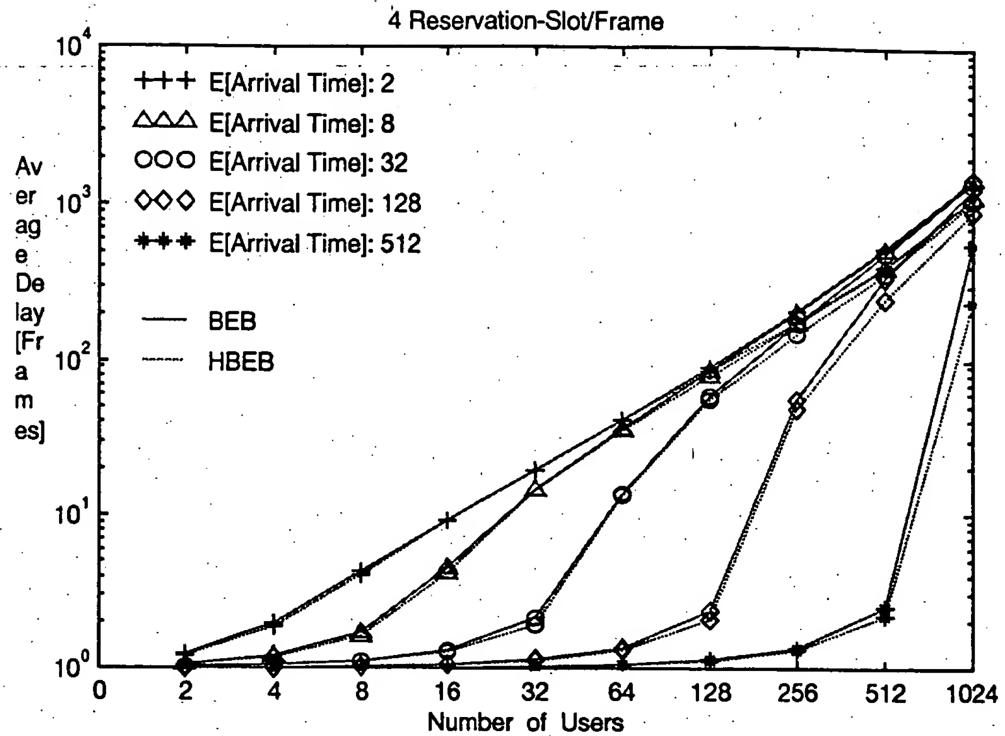

Figure – 21.

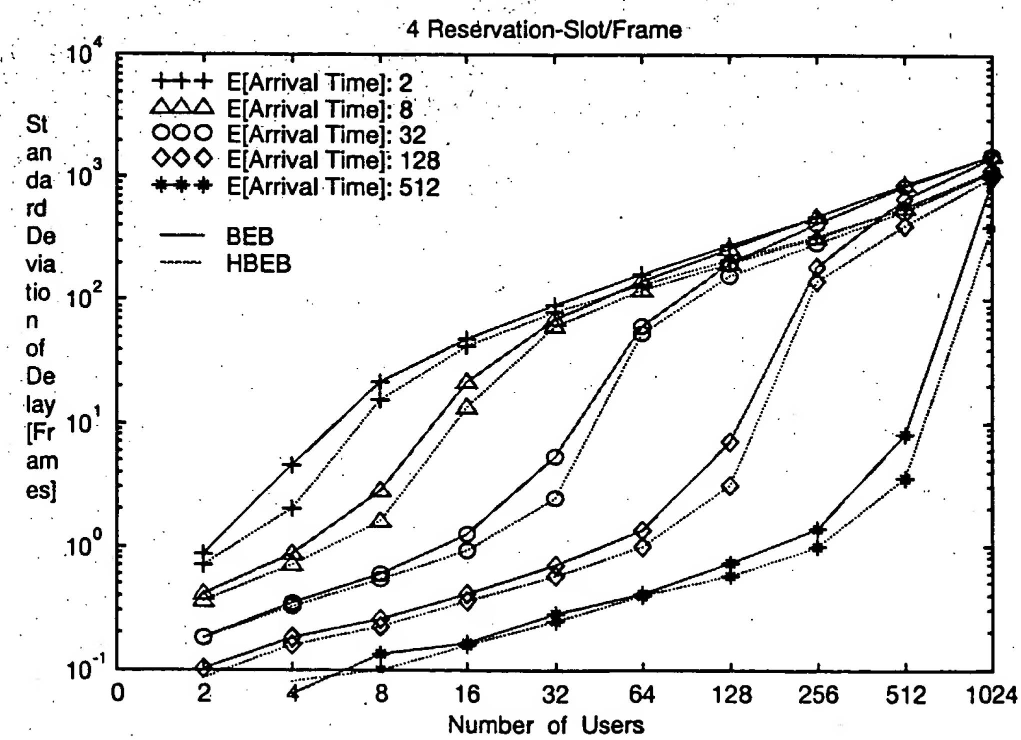

Figure – 22.

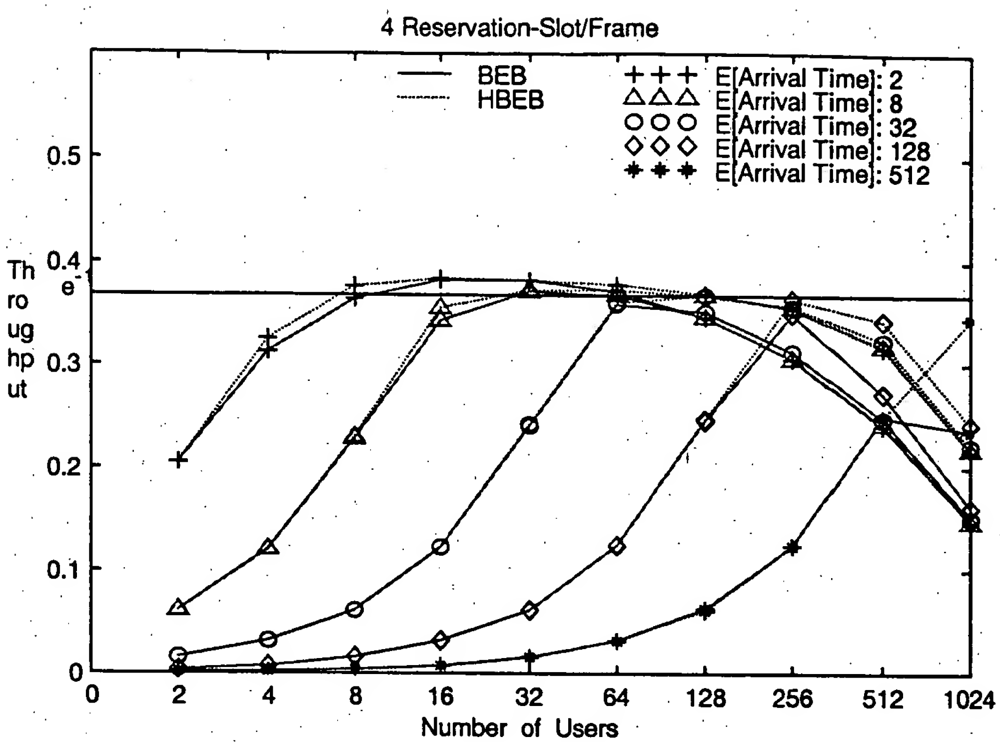

Figure – 23.

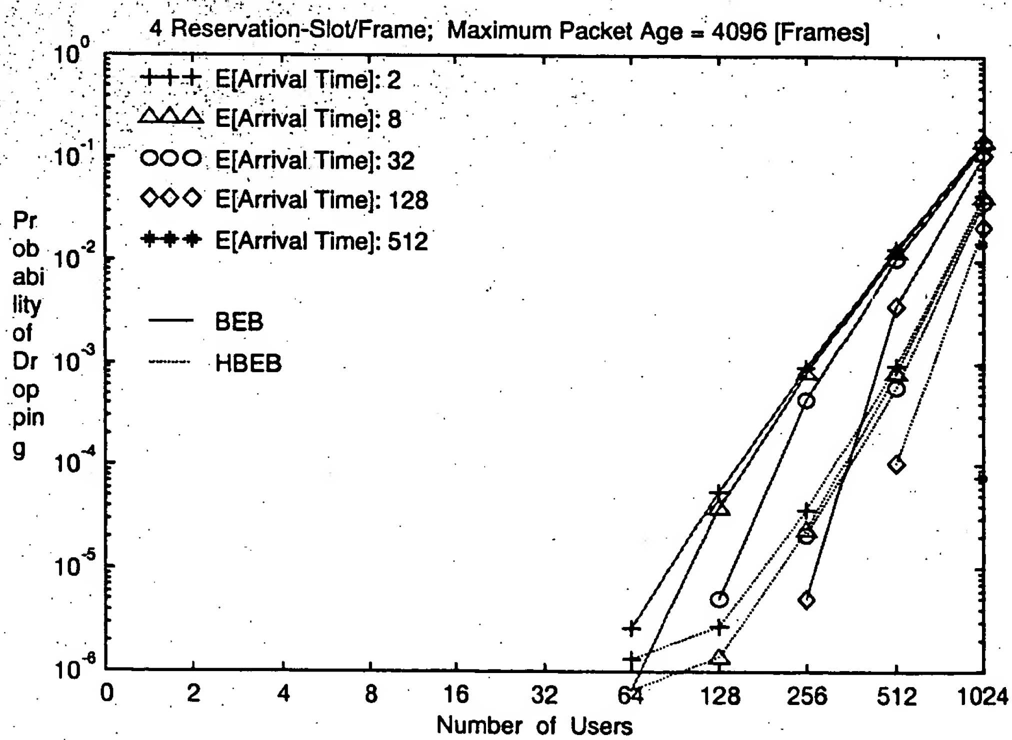

Figure – 24.

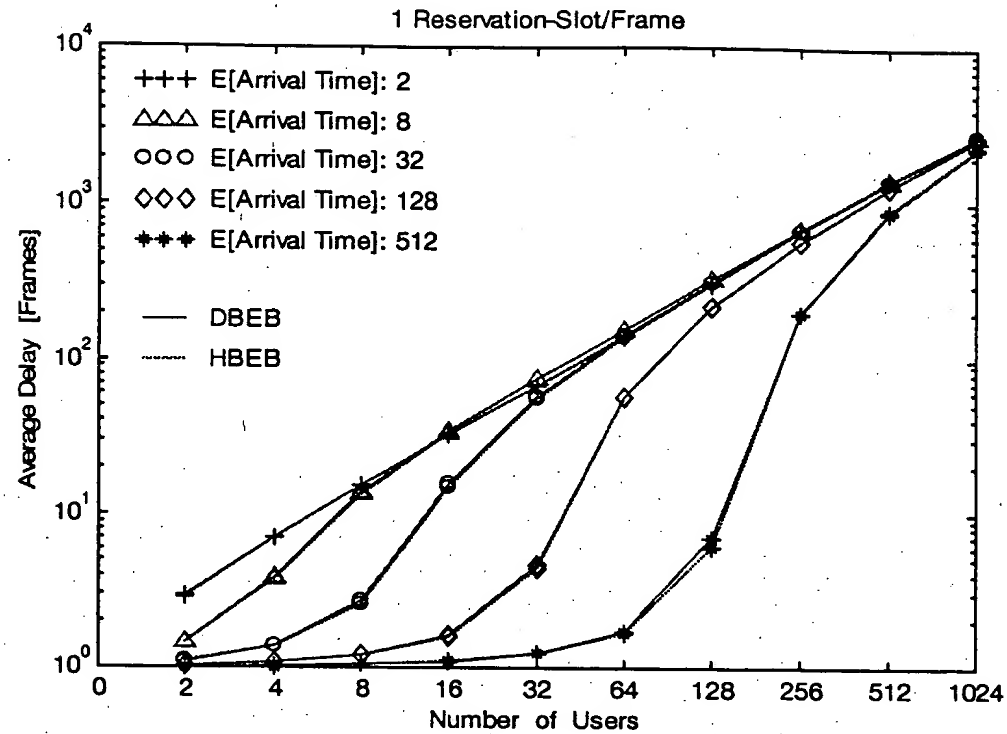

Figure – 25.

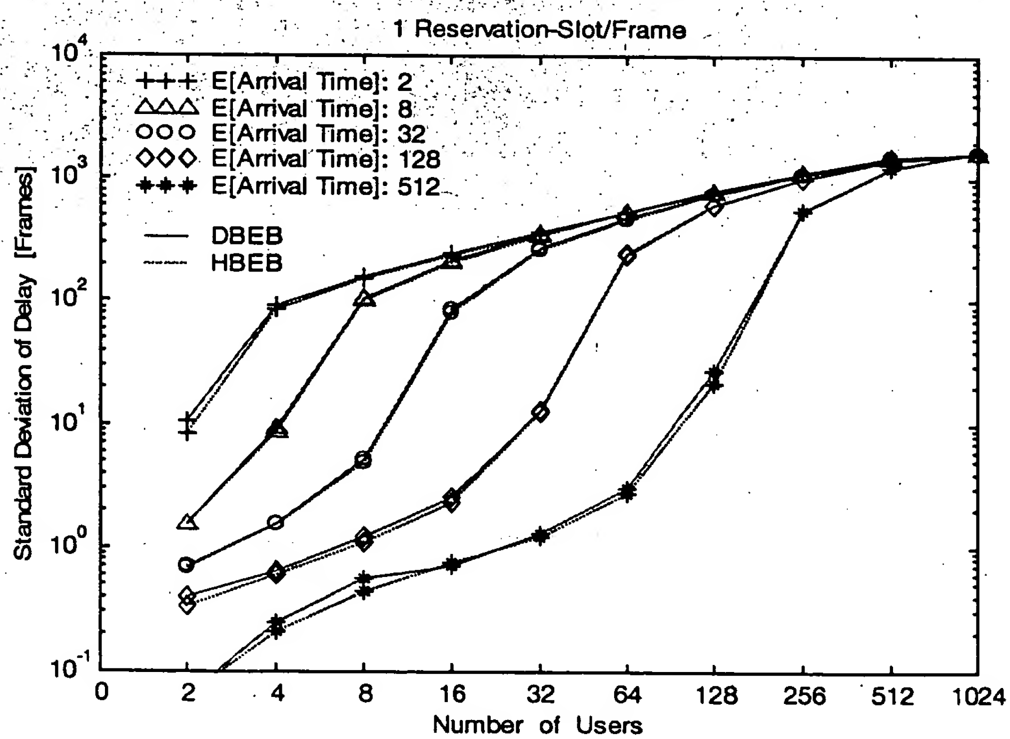

Figure – 26.

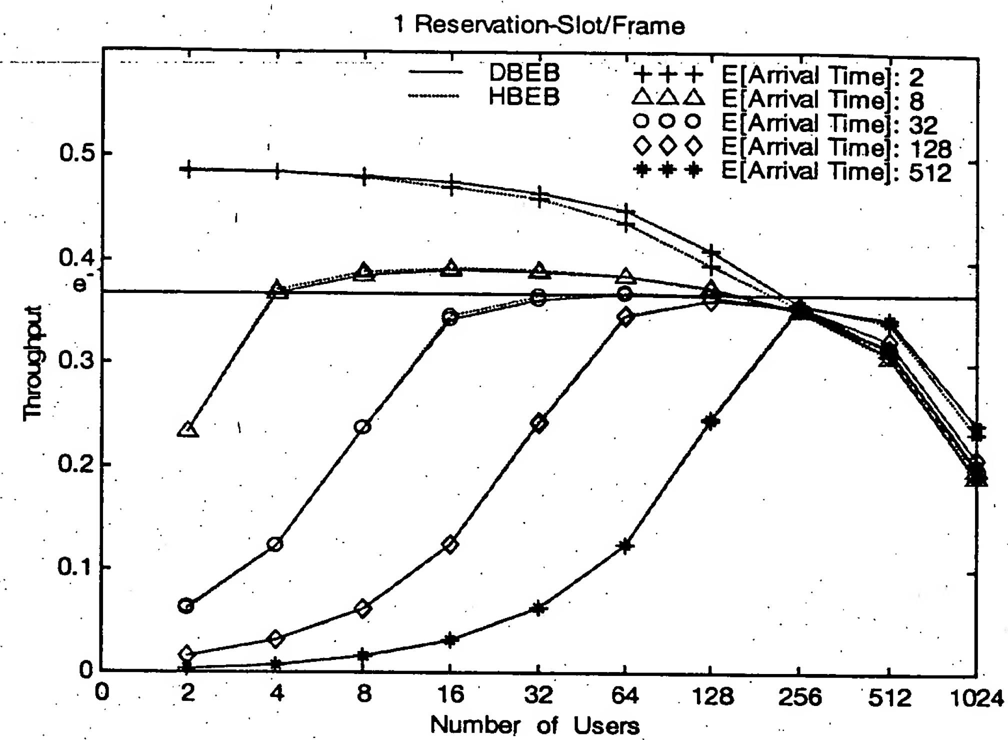

Figure – 27.

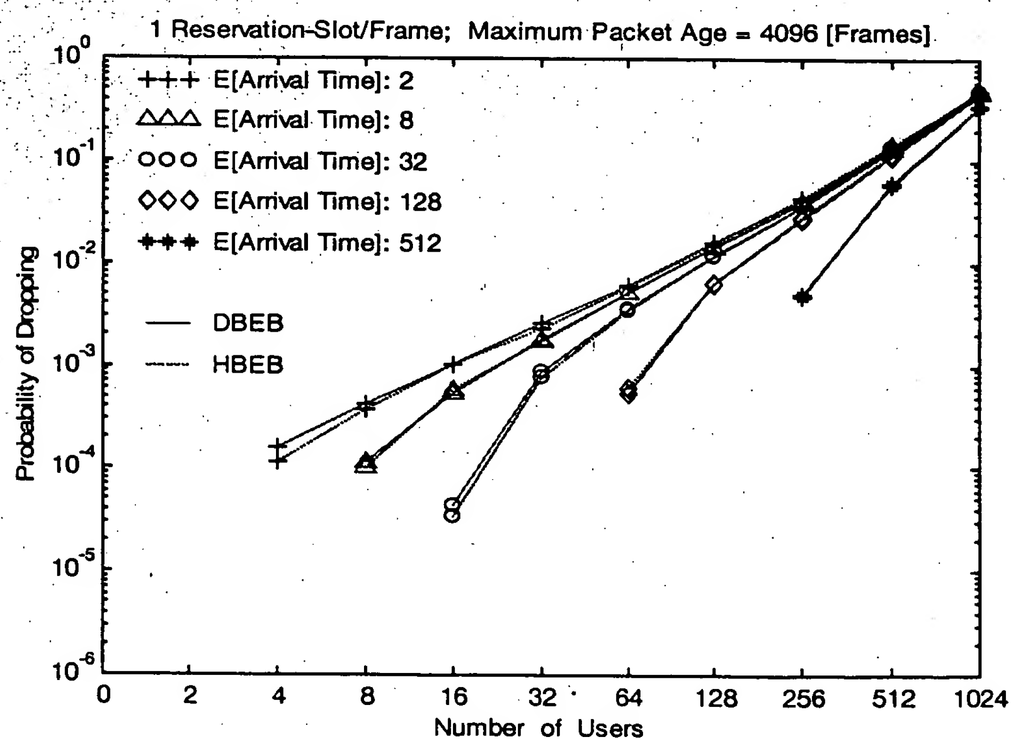

Figure – 28.

From Figure-1, we observe that there is only minor difference between DBEB and BEB when number of users is less than 32. However, when the number of users is larger than 128, DBEB significantly decreases the average delay. Under almost all the simulation results we obtained, DBEB performs better than BEB. The only case where BEB outperforms DBEB is when the number of users is equal to 128 and the mean arrival time is equal 512 frames, though the difference is negligible.

Standard deviation of delay stands for the level of equitable resource allocation. As we have mentioned before, BEB brings up the problem of capture effect and a few of the users could dominate most of the available bandwidth. Under such situation, some of the reservations have very small delays, while the others have very large delays, and this results in a large standard deviation of delay and an unfair allocation of available bandwidth. As we can see from Figure-2, DBEB always has smaller standard deviation of delay when number of users is less than 1024. This means DBEB shares the medium in a fairer way among contending users than the traditional BEB does. In particular, when there are 8 users and mean arrival time is 32 frames, BEB has a standard deviation of 10.1 and DBEB has a standard deviation of 5.2, an improvement of 49%. In addition, when 32 users are contending and mean arrival time is 128 frames, BEB and DBEB have a standard deviation of 22.8 and 13.0 respectively, a 43% improvement. The only case where BEB performs a little bit better than the DBEB occurs when there are 1024 users contending the bandwidth.

In this memorandum, throughput is defined as the average number of successful reservation per reservation slot. Figure-3 shows that DBEB always has equal or higher throughput than traditional BEB. In particular, when there are 1024 users contending the reservation slots, BEB has a throughput of less than 0.08, while DBEB maintains the throughput at a level of at least 0.2.

Probability of dropping is defined as the ratio of number of expired and dropped reservations to the number of total reservations. In this memorandum, we assume the maximum packet age is 4096 frames. If a packet exists for more than 4096 frames and its reservation is not successfully made, the reservation is dropped. Figure-4 shows that, except for two cases, DBEB has a lower probability of dropping than BEB does. For example, when there are 16 users and mean arrival time is 32 frames, probability of dropping for BEB and DBEB is 8.9e-5 and 4.36e-5 respectively, a 51% improvement. When the number of users is 64 and mean arrival time is 128 frames, DBEB improves BEB for 55%.

Figure-5 to Figure-12 compare BEB and DBEB for the case of 2 and 4 reservation slots per frame. Comparisons between BEB and HBEB are shown from Figure-13 to Figure-24 and have similar trends as those of between BEB and DBEB.

When comparing DBEB and HBEB, we found that their performances are very similar. For the case of 1 reservation slot per frame, the comparisons are shown in Figure-25 to Figure-28.

V. Summaries

In this memorandum, we proposed two back-off algorithms, DBEB and HBEB, to improve the performance of traditional BEB. ~~BEB has a well-known problem of capture effect~~ that a few of the users may dominate the whole available bandwidth. In addition, traditional BEB allows new arrivals to contend the medium immediately and this could worsen the probability of collision if the traffic has been heavy. Both DBEB and HBEB try to alleviate the problems by decreasing back-off window size growing rate and increasing back-off window size for newly initiated reservations. Simulation results prove both schemes outperform the traditional BEB most of the time.

Reference:

1. V. K. Garg, K. Smolik, J. E. Wilkes, "*Applications of CDMA in Wireless/Personal Communications*", Prentice Hall, 1997.
2. David J. Goodman, "Packet Reservation Multiple Access for Local Wireless Communications," *IEEE Trans on Comm.*, Vol. 37, No. 8, pp. 885-890, Aug. 1989.
3. David J. Goodman, and Sherry X. Wei, "Efficiency of Packet Reservation Multiple Access," *IEEE Trans. Vehic. Technol.*, Vol. 40, No. 1, pp. 170-176, Feb. 1991.
4. M. Thomas, and D.J. Goodman, " Multi-rate PRMA: A Protocol for Controlled Soft-capacity in TDMA Systems," *IEE Electronics Letters*, Vol. 32, pp.1344-1345, July 1996.
5. Sanjiv Nanda, David J. Goodman, and Uzi Timor, "Performance of PRMA: A Packet Voice Protocol for Cellular Systems," *IEEE Trans. Vehic. Technol.*, Vol. 40, No. 3, pp. 584-598, Aug. 1991.
6. Sanjiv Nanda, "Stability Evaluation and Design of the PRMA Joint Voice Data System," *IEEE Trans. Comm.*, Vol. 42, No. 5, pp. 2092-2104, May 1994.
7. S. Tasaka, "Stability and Performance fo the R_AHOHA Packet Broadcast System," *IEEE Trans. Comput.*, Vol. C-32, pp.717-726, Aug. 1983.
8. F. Delli Priscoli, Giovanni Picciano, Fabrizio Sestini, "Dynamic Carrier Allocation in a PRMA Cellular Network," *Proc. Of the IEEE BLOBECOM '95 Conference*, Singapore, pp. 1157-1161, November 1995.
9. Deborah A. Dyson, and Zygmunt J. Haas, "A Dynamic Packet Reservation Multiple Access Scheme for Wireless ATM", *IEEE Milcom'97*, Monterey, CA, Nov. 2-5, 1997.
10. M. Thomas, and D.J. Goodman, "Multi-rate PRMA: A Protocol for Controlled Soft-capacity in TDMA Systems," *IEE Electronics Letters*, Vol. 32, No.15, pp.1344-1345, July 1996.
11. M. J. Karol, Z. Liu, and P. Pancha, "The Design and Performance of Wireless MAC Protocols," Lucent Technologies Proprietary, Document No. BL0113430-971024-10TM.
12. M. J. Karol, Z. Liu, and K. Y. Eng, "Distributed-Queueing Request Update Multiple Access (DQRUMA) for Wireless Packet (ATM) Networks," *ICC'95 Conference Record*, Seattle, USA, pp.1224-1231, June 1995.
13. N. Amitay, and L. J. Greenstein, "Resource Auction Multiple Access (RAMA) in the cellular Environment," *IEEE Trans. On Vehic. Tech.*, Vol. 43, No. 4, pp. 1101-1111, Nov. 1994.
14. N. Amitay, and L. J. Greenstein, "Resource Auction Multiple Access (RAMA) in the cellular Environment," AT&T Proprietary, Document No. BL011344-930923-09TM.
15. N. Amitay, and S. Nanda, "Resource Auction Multiple Access (RAMA) for Statistical Multiplexing of Speech in Wireless PCS", *IEEE Trans. On Vehic. Tech.*, Vol. 43, No. 3, pp.584-596, Aug. 1994.
16. M. J. Karol, and C. L. I, "A Protocol for Fast Resource Assignment in Wireless PCS", *IEEE Trans. On Vehic. Tech.*, Vol. 43, No. 3, pp. 727-732, Aug. 1994.
17. K. C. Chen, C. H. Lee, "RAP – A Novel Medium Access Control Protocol for Wireless Data Networks," *Proceeding IEEE Globecom'93*, pp. 1713-1717, 1993.
18. K. C. Chen, and C. H. Lee, "Group Randomly Addressed Polling for Multi-Access Wireless Data Networks," *IEEE Int. Conf. Comm.*, pp. 913-917, New Orleans, 1994.
19. J. Sanchez, R. Martinez, and M. W. Marcellin, "A Survey of MAC Protocols Proposed for Wireless ATM," *IEEE Network*, pp. 52-62, Nov./Dec. 1997.
20. A. S. Tanenbaum, "*Computer Networks*", 3rd Edition, Prentice Hall, 1996.
21. Y. D. Lin, C. Y. Huang, and W. M. Yin, "Allocation and Scheduling Algorithms for IEEE 802.14 and MCNS in Hybrid Fiber Coaxial Networks," *IEEE Trans. On Broadcasting*, Vol. 44, No. 4, pp. 427-435, Dec. 1998.
22. D. Bertsekas, R. Ballager, "Data Network," 2nd Edition, Prentice Hall, 1992.

23. G. Fayolle, E. Gelenbe, and J. Labetoulle, "Stability and Optimal Control of the Packet Switching Broadcast Chane," *J. Assoc. Commput. Machinery*, Vol. 24, No. 3, pp. 375-386, July 1977.
24. B. Hajek, and T. v. Loon, "Decentralized Dynamic Control of a Multiaccess Broadcast Channel," *IEEE Trans. Automat. Contr.*, vol AC-27, No. 3, pp. 559-569, June 1982.
25. S. C. A. Thomopoulos, "A Simple and Versatile Decentralized Control for Slotted ALOHA, reservation ALOHA, and Local Area Networks," *IEEE Trans. Comm.*, Vol. 36, No. 6, pp. 662-674, June 1988.
26. G. A. Cunningham, III, "Delay Versus Throughput Comparisons for Stabilized Slotted ALOHA," *IEEE Trans. Comm.*, Vol. 38, No. 11, pp. 1932-1934, Nov. 1990.
27. M. Bassiouni, M. Georgiopoulos, M. Chiu, and R. Guha, "Performance of Standard and Modified Network Protocols in Real-Time Application," Proceedings of the *1997 IEEE Intern. Perform., Comp., and Comm. Conference*, pp. 26-32, 1997.
28. S. Deng, "Capture Effect in Residential Ethernet LAN," *Proceedings of IEEE Globecom*, pp. 1678-1682, 1995.
29. M. L. Molle, and K. J. Christensen, "The Effects of Controlling Capture on Multimedia Traffic for Shared Ethernet Systems," *Telecommunication Systems*, pp. 287-314, 1998.
30. K. J. Christensen, "A Simulation study of Enhanced Arbitration Methods for Improving Ethernet Performance," *Computer Communications*, pp. 24-36, 1998.